Which came first: The Cell or the Membrane?

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Membranes are a ubiquitous phenomenon in biological systems. Every cell has a plasma membrane, and most have intracellular membranes which surround organelles and, in some cases, themselves constitute organelles.

Biological membranes differ in each cell, and indeed, within the cell itself, on the level of molecular composition. The similarities, however, not only in composition, but also in physical and chemical behaviour, morphology (as seen, for example in the electron microscope), and general biological properties, are striking.

Cell membranes are essential components of the living cell. It is this barrier which sequesters the living metabolizing cytoplasm from the external environment. When we chemically degrade the membrane of the erythrocyte, for example, the cell matter simply spills out into the aqueous surroundings. Bacteria, and plant cells, which are surrounded by thick cell walls also lose their viability unless their cell membrane is intact. Compartmentation is only one of many varied and elegant functions which can be ascribed to membranes, yet clearly illustrates their vital role in the living process.

These similarities have prompted the construction of a number of general membrane models to explain the similar membane characteristics in terms of a general molecular structure.

The evolution of the membrane as a function of the history of life itself is one of interest. Does the present similarity of membranes reflect a common precursor, or the common result of an evolutionary development in search of the best system to fulfil common needs? Were cells once extant which had other systems for compartmentation and selective permeability?

Who came first - the cell or the membrane?

Although any conclusions on the question are impossible to verify, the teleological implications are of interest. If, indeed, the membrane evolved in cells already viable and functioning, perhaps the membrane can indeed be thought of as an organelle whose structure arose in response to functional needs which exist to the present. On the other hand, recent experiments, mostly in the research of artificial membranes, indicate that the formation of closed membranes, ~~such as~~ similar to the biological ones we know know, can be spontaneously generated, in aqueous solution. It could then be that instead of being the result of biological development, a simple membrane, different perhaps in composition but similar in morphology to the general model which exists today, was a motive force for biogenesis itself. If the membrane was a morphological precursor in prebiological systems, our appreciation of its univeral biological presence takes on more of a historical role than a mere functional one.

~~Agreement on the simplest form of life has~~ not been ~~reached~~.

The definition of the living cell ~~is~~ a difficult one. A standard differentiation between the living and the non-living is the ability to reproduce. According to this definition, viruses are alive only when they invade a host cell. They then reprodcue inside the cell framework. This definition is complicated by a recently-discovered bacteria, Bdellovibrio bacteriovorus, which has an intact membrane and a ~~f~~ metabolizing cell, as we know it, with one exception. This ~~xxxxxxxx~~ tiny microorganism ~~even on~~ predates on other bacteria, invading them. It is only within another host cell that it is able to reproduce. Once outside the host cell, it behaves similar to any other microorganism, not actively engaged in replication. When it does not invade a host cell it does not have the ability to reproduce and is therefore not viable. It then ~~takes~~ assumes the status of a dormant virus cell, which it is anything but similar to. The weaknesses of this argument are self-evident

An easier path to take is to define the cell in structural terms. And since every known livign cell has at least a cell membrane (plasma membrane) (even Bdellovibrio bacteriovorus) can be construed as its presence ~~is~~ a condition for a living cell. ~~In this instance~~, With this definition the question of whether the cell preceded the membrane is meaningless. After all, without a cell membrane, there is no cell. So how could the cell have existed without a membrane?

~~In order to avoid xxix the danger of being meaningless, we must first define what we mean here as a living cell.~~

Because the membrane is a sine qua non component of systems considered as living today, this does not mean that somewhere in evolutionary history other types of membranes existed, or even phase boundaries which fulfilled the similar role* these ~~cells~~ systems were capable of metabolism + reproduction. Perhaps one or some of them developed the membrane structure we now recognize as the general one. Alternatively perhaps different organisms developed.

* Such will be discussed further on.

One postulates

The theory of chemical evolution depicts the beginning of life as we know it to be a process of chemical development in the primeval bodies of water, which took place for over a billion years, before such primitive unicellular organisms as the blue-green algae evolved. → Kenyon + Swenson. The development of basic biochemical systems is seen as a random process involving chemical reactions which followed certain non-equilibrium thermodynamic laws. (Prigogine) Katzir, A.

The morphological problem in chemical evolution is problematic. How did microscopic segments of the primeval ocean, albeit rich in organic molecules and chemical reactions, slowly take on characteristics separate from its immediate environment?

Actually, the answers can be numerous. The separation of phases from an aqueous organic solution is not a miracle, but the consequence of thermodynamic predictions. Even such simple inorganic systems as a crystal of ferricyanide in copper sulfate solution. The crystals swells with water and an osmotically-sensitive membrane can be observed. (Traube)

A. I. Oparin has used coacervates as a likely model for the basis of morphogenesis. → C.D. of life Upon heating mixtures of polypeptides, starch, and histones at a definite pH (6-6.2) thepolymers congeal to form little coacervate drops. These drops are capable of enzymatic activity (provided that the particular enzyme is included in the system) and can be seen to bud, and thus divide. They also represent take polymers out of the solution and thus are a great concentrating factor.

Oparin, in his famous monograph, ignores almost completely the existence of the cell membrane. There is good reason for this. As In his logical development of the cell, there is no justification for the development of a membrane. The very phase barrier between

Oparin p45 → "When there are high-polymeric organic substances present in the aqueous solution itself, the separation out of individual systems demarcated from their environment occurs even more simply

First studied by Bungenberg de Jong, H. G. Proc. Acad. Sci. Amster. 50, 707 (1947), / Protoplasma, 15, 110, 1932.

the gelled polymers and the aqueous solution exhibits selective permeability. Compartmentation is due to the separate phases. No need for lipid-protein membrane

Nothing resembling coacervates can be found in biological cells today. Even the blue-green algae, considered a primitive life-form, possesses a fluid, soluble cytoplasm, surrounded by a cell-membrane.

Since Oparin's work w/coacervates the ubiquity of the cell membrane has been recognized, largely through electron-microscope work. It would stand to reason, in view of present knowledge, that the role of ~~protein and/or lipid~~ PRIMITIVE membranes in the history of chemical evolution is determinant.

The experimental basis for primitive membrane systems has been firmly established. Mixtures of amphipathic molecules in water often yield, upon mechanical agitation, closed vesicles, the aqueous region surrounded by a bimolecular leaflet, similar to that found in living cells. The formation of such vesicles arises because it is a minimal energy configuration.
based upon the behaviour of amphipathic molecules (such as long chain alcohols, fatty acids, polar lipids) in aquoeus solution. A.S.C. Lawrence
Although these polar hydrocarbon molecules are initially not miscible upon addition to water or brine, upon mechanical shaking they disappear into solution and float on the surface. Microscopic examination reveals that ~~for thermodynamic reason~~ the molecules form low-energy aggregates among which closed bimolecular vesicles are found. Lipid mixtures extracted from cell membranes, and isolated cell membranes themselves show similar behaviour. Bangham, Philips, Goldacre

Rabaté without is in suspension

~~Both the~~ hypotheses ~~of the coacervate~~

It has thus been postulated, that, given the hypothesis of the presence of an organic soup in primeval times, rich in organic molecules, such vesicles could have been created by a variety of natural mechanical disruptions Goldacre.

. The very creation of these vesicles separated the aqueous phase within from that without, ~~This~~ is separated by a semi-permeable barrier. This, in turn, may have led to an increasing disparity between concentrations and chemical species within vesicels, and without. Water, entering the vesicles could cause them to expand and burst, forming new vesicles of the same composition and characteristics, Eventually some sort of primitive metabolism may have arisen, involving relatively simple catalytic agents. perhaps ~~as~~ underlying the membrane surface itself is a template. → Mention reaction probability, N.K. Adam.

The issue of morphogenesis is central xx. If Oparin's coacervates later developed into living cells, when was a protein-lipid layer adsorbed? If itx was at a stage when these cells were indeed capable of metabolizing and reproducing, why xxx was the late-stage addition of the membrane so necessary, that any organisms (if such did, indeed , exist) were eventually selected xxixxx against in evolutionary development, otherwise they would still be around today.

What we see, today, however, has no relation whatsoever to a coacervate. The cytoplasm xx is liquid in most cells, and the xxxxixxx semi-permeable barrier between xx the cell and the environment constitutes a separate phase. Indeed, today's life forms indicate that their logical morphological ancestor was a vesicle, which concentrated within the early developing chemical systems.

If this is the case, then the membrane came first, and the cell was a consequence.

But Did this primitive membrane bear resemblance to the present generally accepted protein-lipid bilayer?

These primitive membranes could have been created out of a variety of amphipathic molecules. Today, xxxxxxxxxxxxxxxxxx most cells synthesize their own major membranal components. These molecules, are in turn specific, being the result of genetic expression. But if we postulate that the membrane came first, then it preceded genetic apparati by a long shot. Which shows that there might have been no connection between the primitive membrane and that later developed.

Some interesting biological phenomena can be instructive. The first is that no organism is known which is capable of de novo synthesis of membranes. If, say, the primitive membrane was a phase barrier, or a polymer, such as polyethylene, and the organisms evolved to develop a lipid-protein membrane, it must have acquired the technique, to do so from scratch. What happened to this genetic ability? It can be argued, it xxxxxxxxx is masked but still exists. If we were to remove a cell membrane, the cell would be able to synthesize a new one, were it not xxx dependent on the previous one to xxxxxx Alternatively, ixxxx the live

If the origin of the present biological membrane lies in biogenesis itself, it follows that the structure and function of the cell itself have always been closely interrelated with a lipid-protein membrane. Thus both the cell and the membrane have evolved to suit one another. Thus, when we marvel today at how suited the membrane is for its functions, at least part of the reason has been adaptation on the part of the rest of the cell to the membrane's gross physical and chemical properties.

A number of cell characteristics can now be examined in terms of the membrane rather than the cell. An example is intracellular water concentration. Bacteria contain up to 90% water (by weight). Why this preponderance of water? Water, it can be argued, is the universal solvent. Any organic chemist knows that reactions in solvent occur much faster than the mixing of two dry reactive powders. Even so, since when has rate been an important factor in biological development? If the development of living microorganisms took well over a billion years, what difference should the rate of metabolism have on the organization of a particular microorganism? Bacteria which were frozen in Antarctica for over 10,000 years have been resuscitated. A. Spores

It could be, however, that primitive cells had no control over the water level. Although biological membranes are impermeable to many molecules, water permeates them freely. The water content of the early organisms was a function of chemical and electric potential. In other words, the ineptitude of the membrane in keeping water out, gave the cell no alternative but to develop structure and metabolism around a high water concentration, Even when life left the ocean, it maintained the necessity for large amounts of water.

Bangham

Another example is intracellular cation concentrations. Cell membranes contain elaborate structures which engage in active, energy-dependent ion transport. Most cells maintain a high concentration of potassium and a low sodium ion level. It is possible that these pumping systems has evolved due to the needs of the metabolism for this specific ionic imbalance. It could just as easily be that during biogenesis, the conditions in the organic soup were those of high potassium and low sodium concentration, and early cells developed their metabolism in these conditions. When conditions changed, the cell was forced to find a process to maintain the ionic status quo. Since the primitive membrane did not distinguish between either ion, it had to further develop the complex lipoprotein pumping units which are active to this day.

could not initially compensate the ionic disparity.

the inability to synthesize membranes can be ascribed to loss of genetic capacity, in view of the fact that once the cell membrane was synthesized, the need for new membranes dissipated. This, is not necessarily true, Eucaryotic cells have various needs for internal membranes for further compartmentation. Mitochondria have two membranes. When the need for an enclosed intracellular body arises, for example in the secretion of hormones, no new membranes are created, The organelles are released in their membrane-bound form from the Golgi apparatus, itself a folded membrane. Why must the eucaryotic cell have adopted such an intricate system for membrane synthesis if it is capable of de novo synthesis. Unless, of course the loss of genetic capacity occured during the evolution of the procaryot, which indeed does not have membrane bound organelles.

The second point is that some organisms, such as the bacteria Mycoplasma

It can be argued that de novo synthesis is lacking in many cases. Bacteria are incapable of de novo synthesis of cell wall. In Eucaryotes mitochondria and chloroplasts are never created, but divide concurrent to cell division. Genes, RNA and protein cannot be (synthesized) without a template. Although this is true in some cases, it is not extensively so. A bacteria with a single polar flagellum divides, giving rise to two progeny, one of which must then synthesize a new polar flagellum where none previously existed.

The second relevant discussion centres around membrane composition. While most cells can depend exclusively on their genetic apparatus for synthesizing the proteins and lipids which they then incorporate into the existing membranes, certain bacteria, for example, Mycoplasma Laidlawii, can incorporate fatty acids from the medium into the membrane without metabolizing them. Stduies with such organisms, as well as mutants, auxotrophic for fatty-acid precursors, have shown that in these cases, the cell membrane can be somewhat modified in both composition and physical characteristics without adversely affecting the viability of the cell.

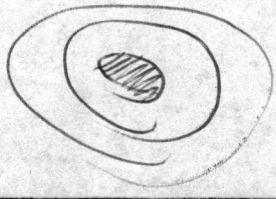
The indication is that even the membranes which exist today are not necessarily completely genetically independent. A certain degree of leeway exists. Membranes supplemented with oleic acid have different characteristics than those supplemented with linolic acid, but both are biologically functional. The implication is that a merger could have taken place between a membrane whose components originated in the extraneous medium and an increasing percentage of components originating in cell metabolism. The main condition being that the gross changes in the molecular structure of the membrane during this transition be minimal.

The other view of the development of membranes would assume that membranes adsorbed to an organism or protoorganism with an already-definite morphology. Since no organisms survived through to the present without one, this adsorption must have given the organism certain evolutionary advantages. Perhaps the lipid protein combination was arrived at as an accident had its rivals but surpassed them. Today's biological membranes are then the result of survival of the fittest, on a micro-biological level. Maybe there once existed a cell with a polymeric semipermeable membrane, such as cellophane. It was well-suited for compartmentation but when food became scarce and other early organisms had acquired the ability for phagocytosis and pinocytosis

but was inefficient in transport ability. Perhaps the membrane composition was more primitive and its functions more basic. However its rise in biological systems, its raison d'etre, must be functional, if it joined an already functioning organism. If this is the case, then we can explain the presence of the membrane, as its composition, as a fulfillment of cellular needs.

Many biologists have done just that. The biological membrane is ept; it is an important component of the cell because it fulfils ten (or twenty) functions which are then ennumerated.

than those we are seeing today.



Most cell membranes show a striking similarity to one another because they fulfill similar roles.

This approach of reconciling cell structure in terms of function is narrow-minded. In recent years it has been suggested that a number of subcellular organelles in eucaryotic cells (notably the mitochondrion (DUNHAM) and chloroplast (BAYER)) owe their origin to a primitive symbiosis: the organelle beinga primitive aerobic bacteria (in the case of mitochondria) which was incorporated by phagocytosis. In this case the mitochondria did not develop with in the cell as a response to functional needs, but was rather the result of an important accident.

The same argument holds for membranes. What if, instead of developing in a metabolizing cell, the membrane the primitive cell developed within a membrane? In this case we should be able to speak of certain cell characteristics deriving from the properties of such a closed bilayer membrane composed of amphipathic molecules.

Let us, then see if we can examine a few cell characteristics in terms of the membrane.

We will never know for certain the details of chemical evolution and the origin of living cells. Similarly we will never be able to ascertain whether membrane vesicles played a crucial morphological role in biogenesis, which has been ascribed them here, or were an evolutionary development. However, the plausibility of the first case carries with it implications. When an attempt is made to explain the ubiquity of the biological membrane, both present function and the possible evolutionary significance should be kept in mind.